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# United States Patent [19] Jokura

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[54] **TDMA MOBILE UNIT FREQUENCY SYNTHESIZER HAVING POWER SAVING MODE DURING TRANSMIT AND RECEIVE SLOTS**

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[63] Continuation-in-part of Ser. No. 46,194, Apr. 12, 1993, abandoned.

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[51] **Int. Cl.<sup>6</sup>** ..... **H04J 3/16**  
[52] **U.S. Cl.** ..... **370/337; 375/375; 455/76; 455/343; 331/25**  
[58] **Field of Search** ..... 370/100.1, 105.1, 370/105.2, 105.3, 108, 95.3, 95.1; 375/354, 371, 375, 376, 373; 455/71, 76, 77, 75, 34.1, 31.1, 183.1, 183.2, 343, 127, 38.3; 331/1 R, 14, 16, 17, 25, 11, 1 A

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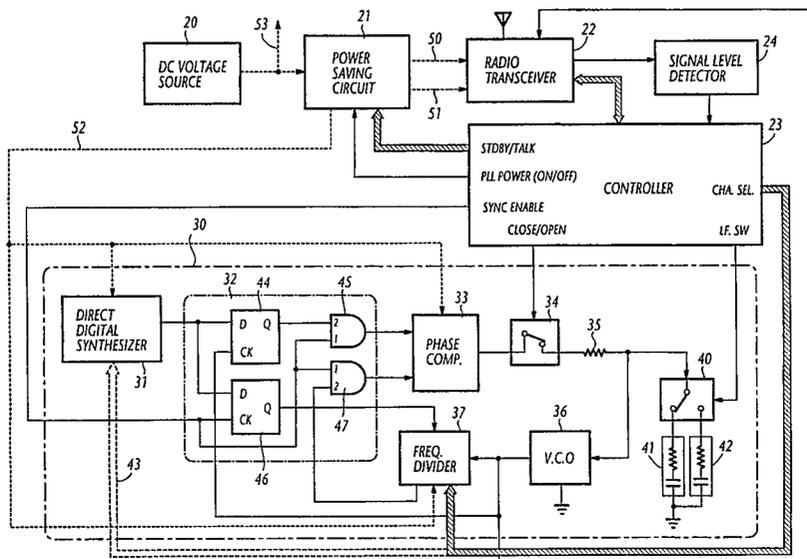
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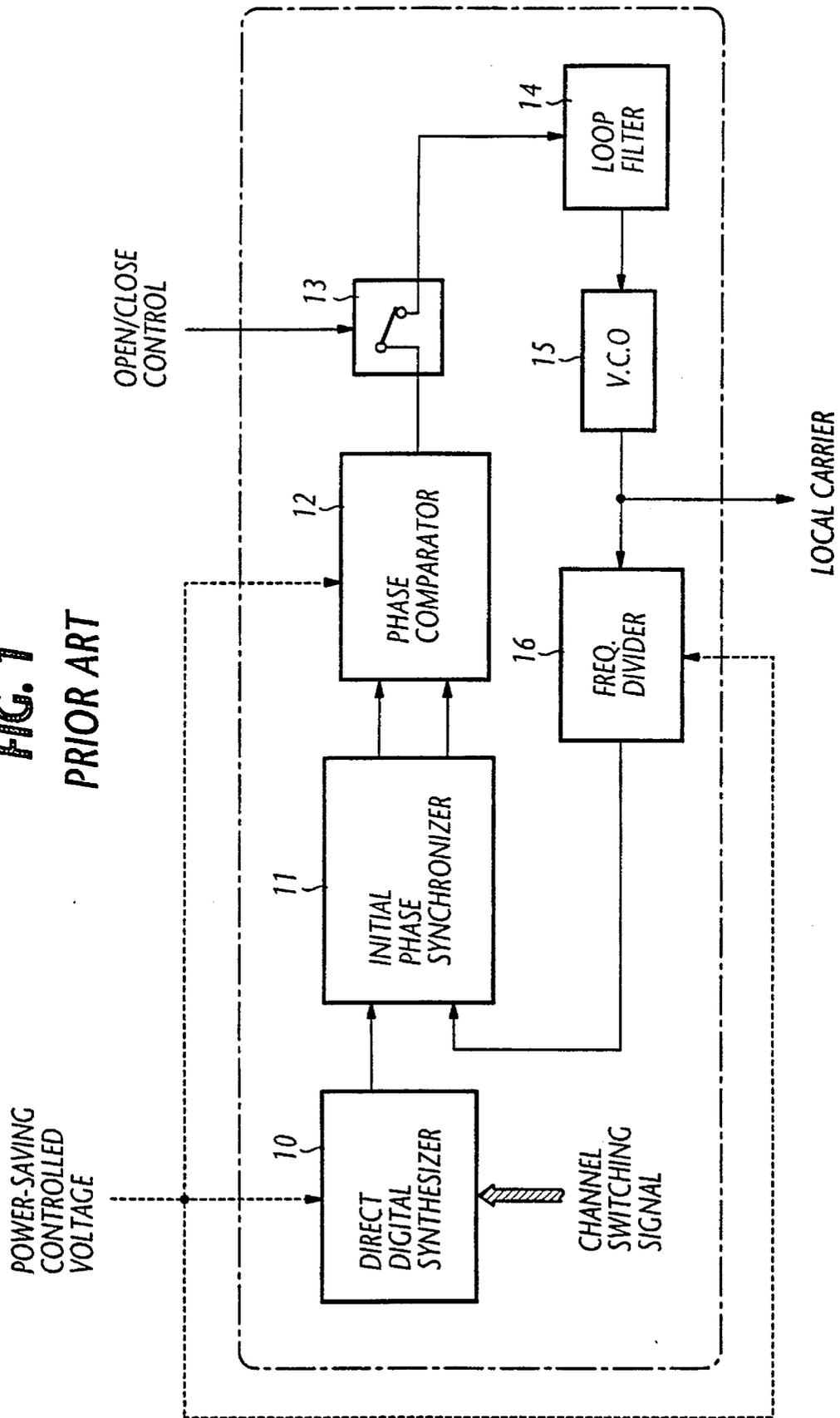
### [57] ABSTRACT

In a frequency synthesizer of a TDMA cellular communication mobile unit, a reference pulse is supplied from a reference pulse source to a phase comparator whose output is coupled through an open/close loop mode switch to a loop filter which is connected to a VCO. A frequency divider produces a submultiple of the VCO frequency and supplies its output to the phase comparator. For power savings purposes, a controller first activates the reference pulse source and the frequency divider and operates the switch to establish a connection between the phase comparator and the loop filter. The controller then operates the frequency divider so that a channel is established between the mobile unit and a first cell site station, and then operates the switch to clear the connection and deactivates the reference pulse source and the frequency divider to allow signals to be exchanged between the mobile unit and the first cell site station during a transmit/receive slot of the channel in a power saving mode. The controller then activates the reference pulse source and the frequency divider, operates the switch to reestablish the connection, and operates the frequency divider during an idle slot of the channel to receive a signal from a second cell site station, and operates the frequency divider so that signals can be exchanged between the mobile unit and the first cell site station during a subsequent transmit/receive slot of the channel.

**2 Claims, 11 Drawing Sheets**



**FIG. 1**  
PRIOR ART



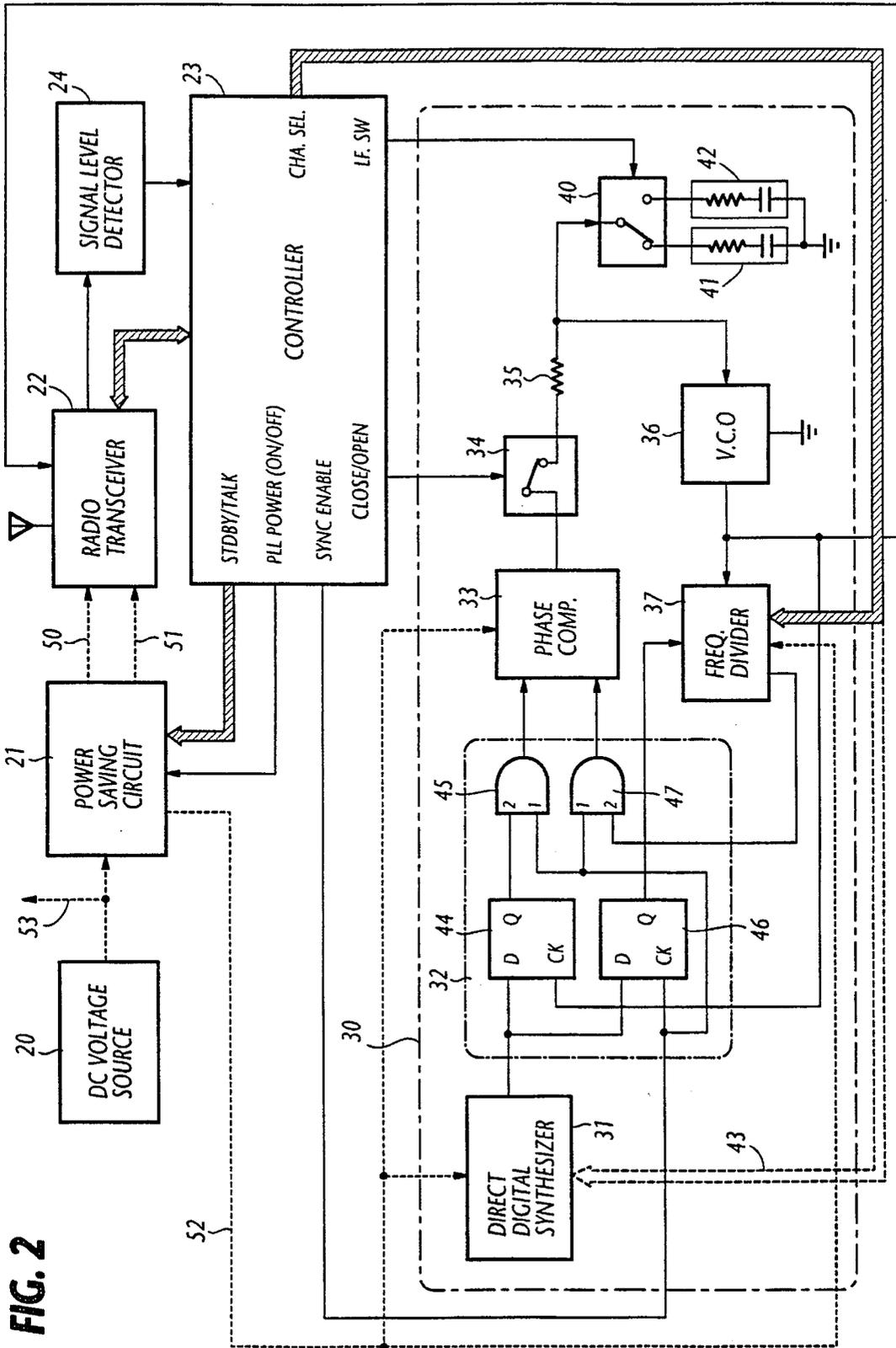
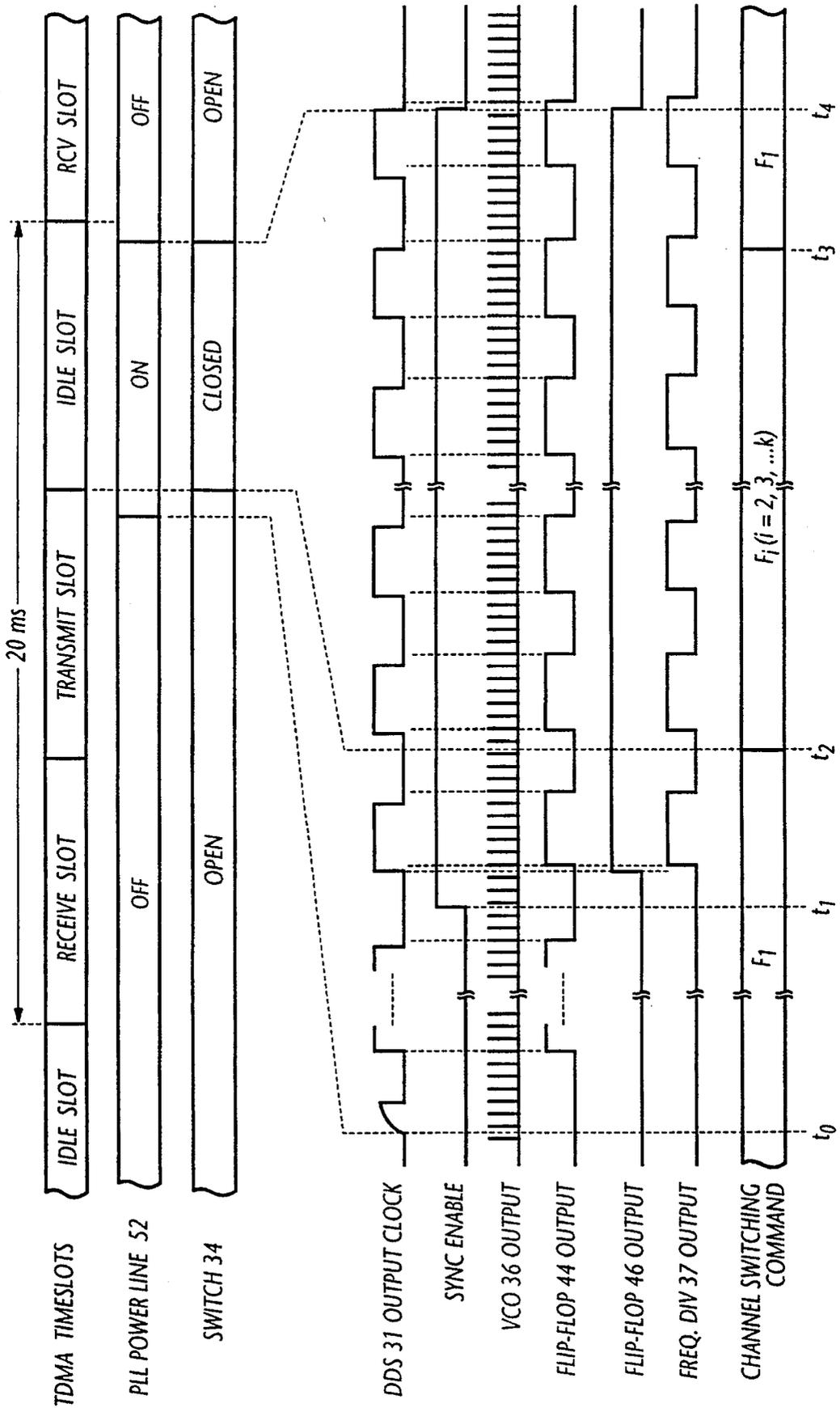
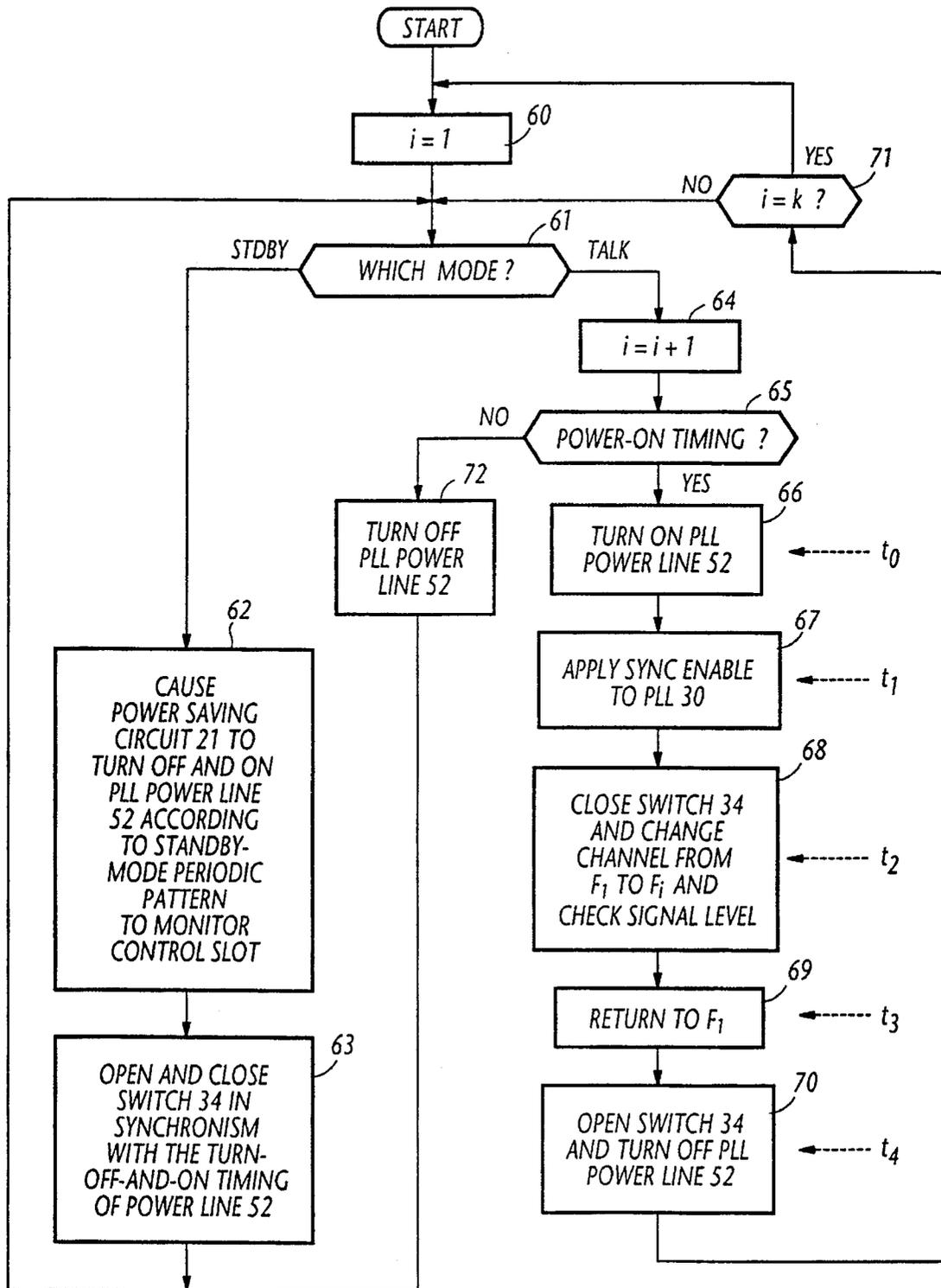


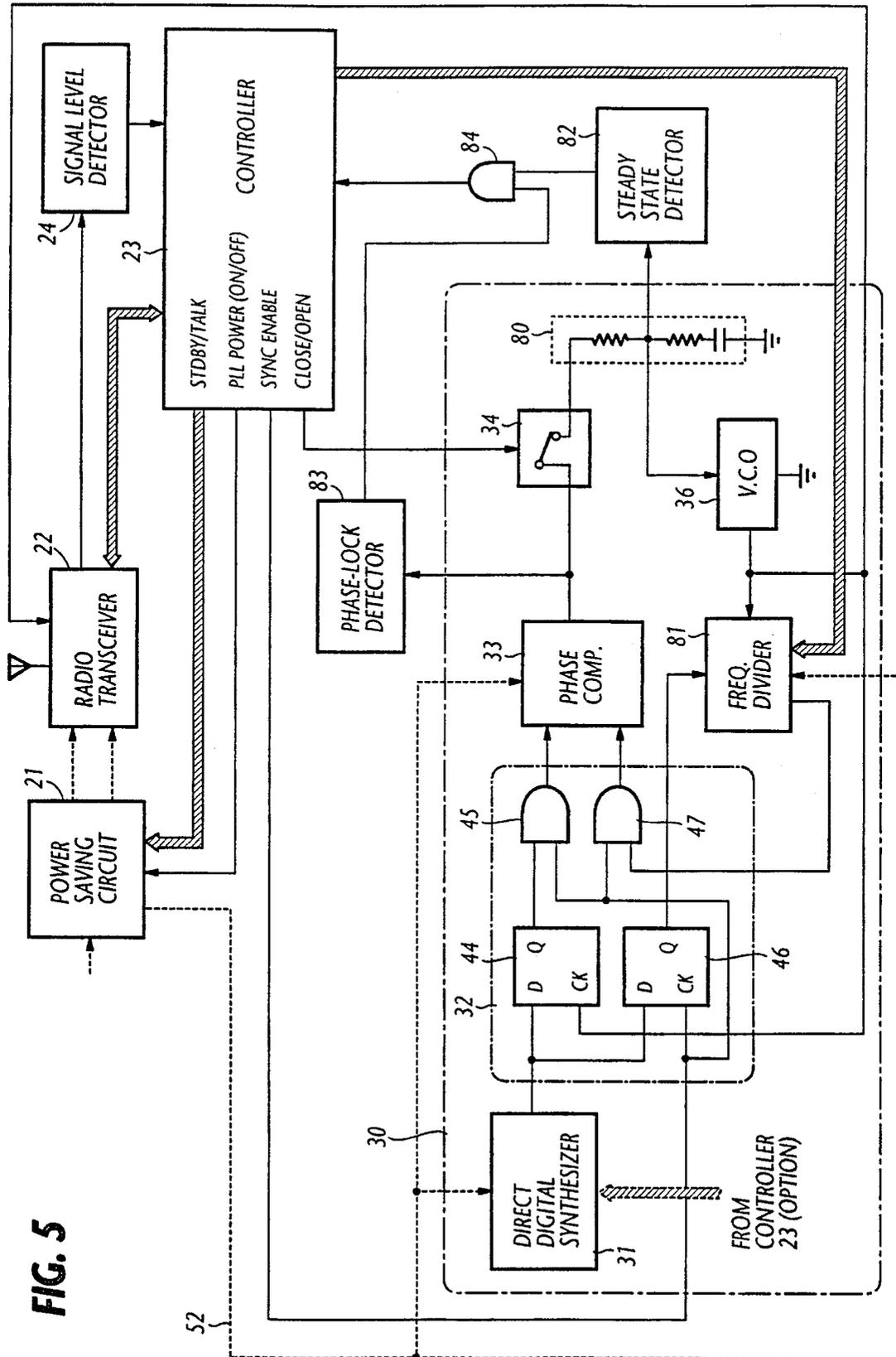
FIG. 3



LEGEND:  
 $F_1$  = FREQUENCY OF CURRENT CELL  
 $F_i$  = FREQUENCY OF ADJACENT CELL  
 ( $i = 2, 3, \dots k$ )

FIG. 4





**FIG. 6**  
STEADY STATE DETECTOR 82

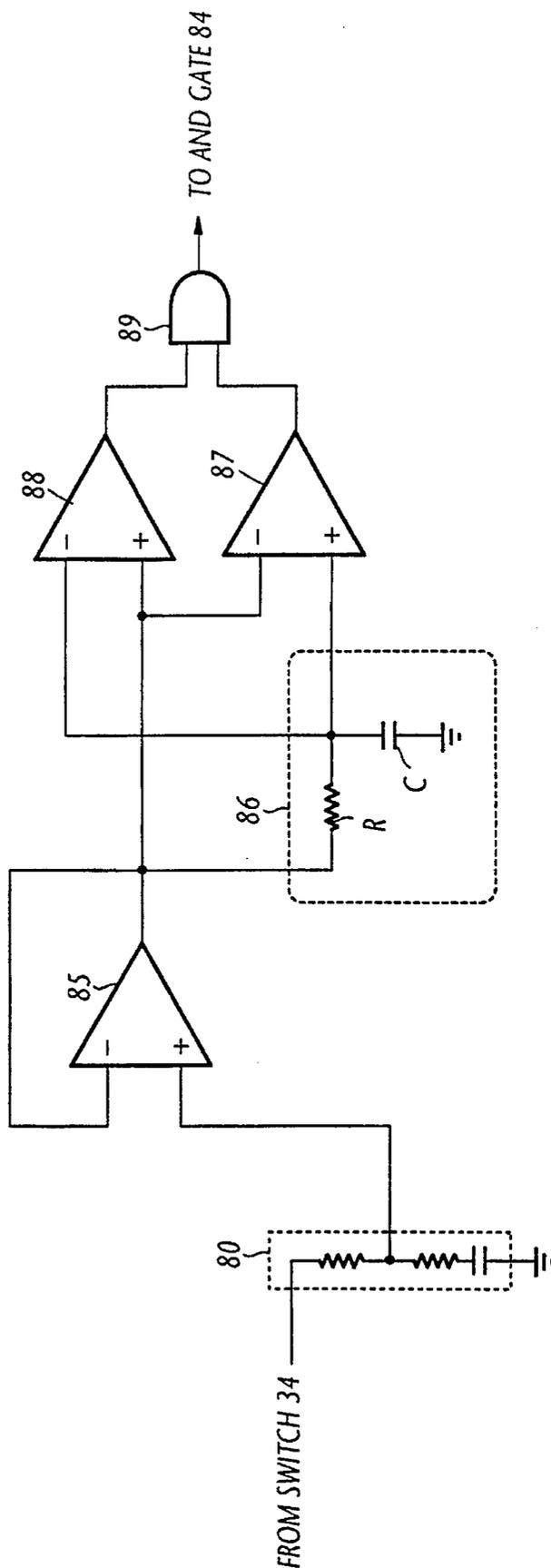
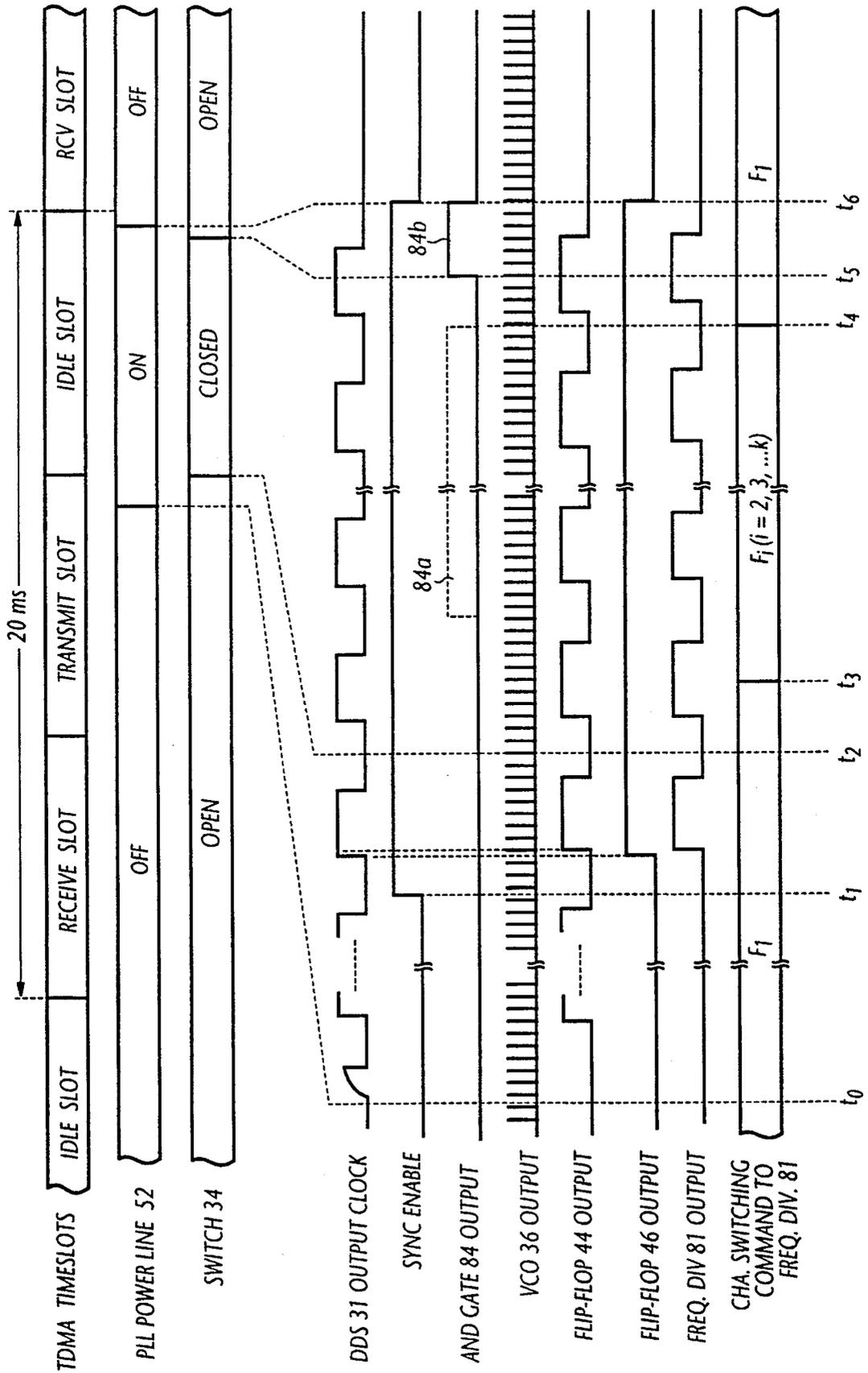


FIG. 7



LEGEND:  
 $F_1$  = FREQUENCY OF CURRENT CELL  
 $F_i$  = FREQUENCY OF ADJACENT CELL  
 ( $i = 2, 3, \dots k$ )

FIG. 8

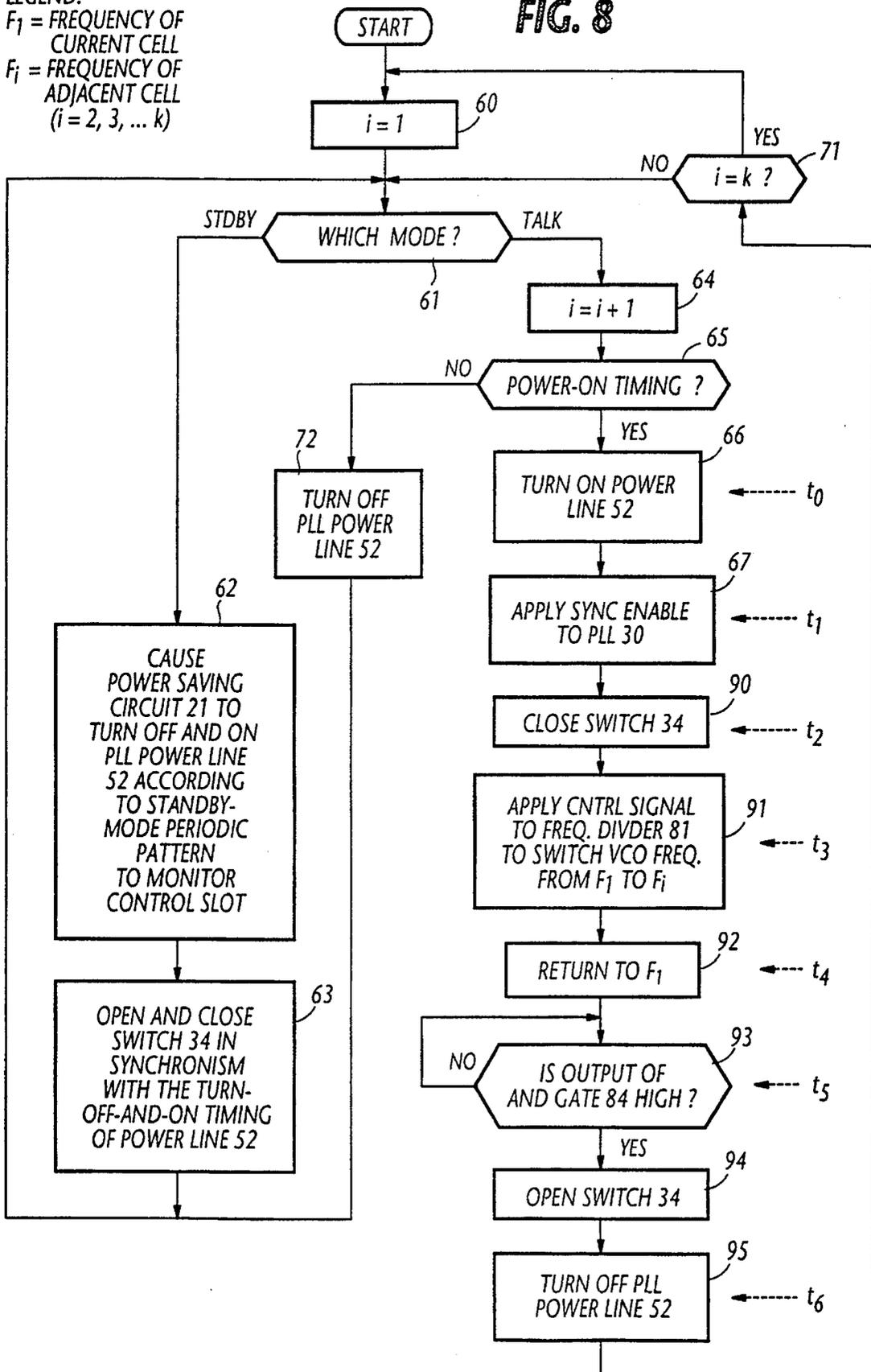




FIG. 10

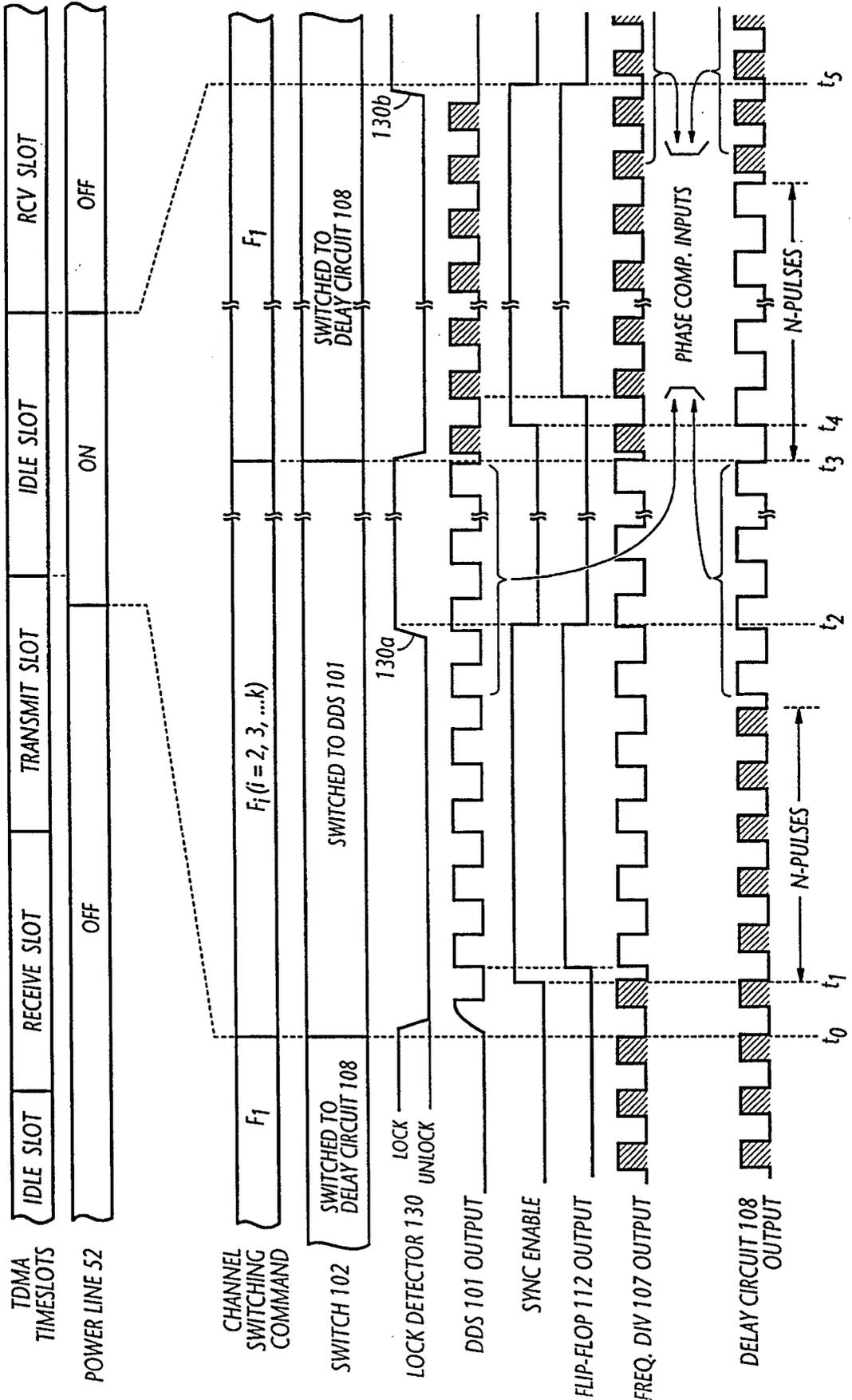
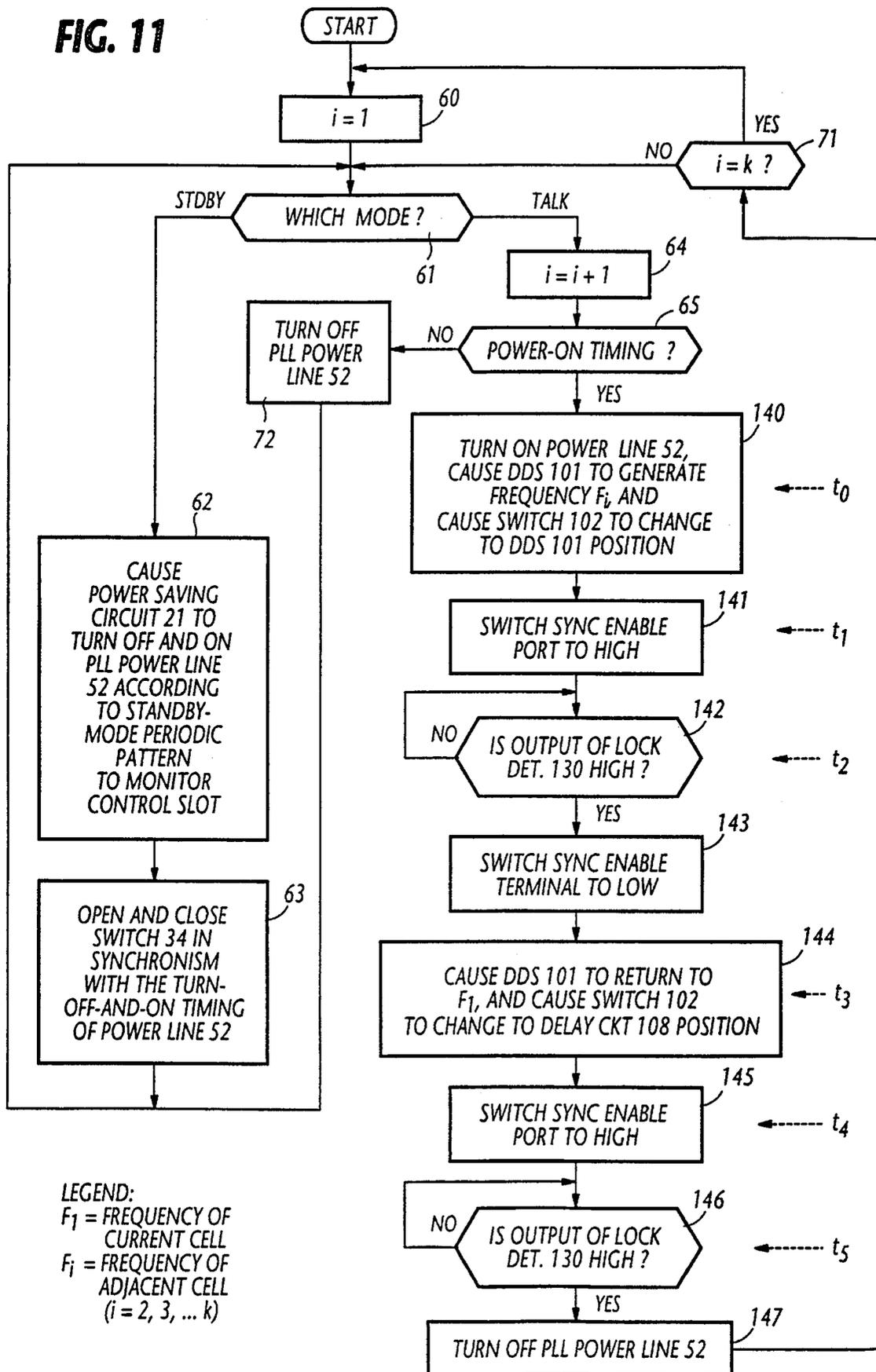


FIG. 11



**TDMA MOBILE UNIT FREQUENCY  
SYNTHESIZER HAVING POWER SAVING  
MODE DURING TRANSMIT AND RECEIVE  
SLOTS**

This is a Continuation-in-Part of application Ser. No. 08/046,194 filed Apr. 12, 1993 now abandoned.

**BACKGROUND OF THE INVENTION**

**1. Field of the Invention**

The present invention relates generally to cellular mobile communications systems, and more specifically to a power saving technique for a mobile unit frequency synthesizer for a TDMA (time division multiple access) cellular communication system.

**2. Description of the Related Art**

As illustrated in FIG. 1, a prior art frequency synthesizer for use in a TDMA cellular mobile communications system includes a direct digital synthesizer **10** that supplies reference pulses to an initial phase alignment circuit **11** to which the output of a frequency divider **16** is also applied to establish phase alignment with the reference pulse. The phase aligned signals are input to a phase comparator **12** where their phase difference is detected and fed via a switch **13** to a loop filter **14**. A voltage-controlled oscillator **15** supplies a VCO output to the frequency divider **16** at a frequency variable with the output of the loop filter **14**. A power-saving controlled DC voltage is supplied to the power-draining units of the frequency synthesizer such as DDS **10**, phase comparator **12** and frequency divider **16** to periodically turn off their power supplies to reduce their energy consumption.

When the mobile unit is in a standby mode in a host cell site area, the power supply to the transmitter is continuously turned off and the power supply to the receiver is periodically turned on and off so as to enable it to monitor the control slot of the TDMA frame of the host cell site. The power-saving controlled voltage is synchronized with the power saving operation of the receiver. During a turn-off period, the switch **13** is turned off to operate the frequency synthesizer in an open-loop mode by feeding the VCO **15** with a voltage developed by the loop filter **14** during the previous turn-on period and currently maintained by the loop filter.

During a talking mode, the transmitter and receiver are alternately turned on during assigned transmit and receive slots of the TDMA frame and turned off during other time slots. The receiver is further turned on during an idle slot of the TDMA frame to enable it to be switched to the channel of an adjacent cell site for a possible hand-off.

Since the mobile unit is required to make a channel search and return to the current channel within a short period of time, the prior art mobile unit cannot turn off the power-draining parts of its frequency synthesizer at a high speed during talking modes. Therefore, the power saving feature of the synthesizer is used only during standby modes.

**SUMMARY OF THE INVENTION**

It is therefore an object of the present invention to provide a frequency synthesizer capable of power savings operation during a talking mode.

In a broader aspect of the present invention, a frequency synthesizer of a mobile unit for a time division multiple access cellular communication system is provided. The

communication system includes a plurality of cell site stations each being assigned a channel of unique frequency for carrying a sequence of transmit/receive slots and idle slots. The synthesizer comprises a reference pulse source, a phase comparator, a loop filter, a voltage-controlled oscillator connected to the loop filter, switch means for establishing and clearing a connection between the phase comparator and the loop filter, and a frequency divider connected to the voltage-controlled oscillator for producing an output at a submultiple of an output frequency of the voltage-controlled oscillator, the phase comparator being responsive to a reference pulse from the reference pulse source and the output of the frequency divider for supplying a phase difference signal to the loop filter. According to the present invention, a power saving method is provided which comprises the steps of:

a) activating the reference pulse source and operating the switch means to establish the connection;

b) operating one of the reference pulse source and the frequency divider so that a channel is established between the mobile unit and a first cell site station;

c) operating the switch means to clear the connection and deactivating the reference pulse source to thereby allow signals to be exchanged between the mobile unit and the first cell site station during a transmit/receive slot of the channel in a power saving mode;

d) activating the reference pulse source, operating the switch means to reestablish the connection, and operating one of the reference pulse source and the frequency divider during an idle slot of the channel to receive a signal from a second cell site station;

e) operating one of the reference pulse source and the frequency divider so that signals can be exchanged between the mobile unit and the first cell site station during a subsequent transmit/receive slot of the channel; and

f) repeating the steps (c) to (e).

According to a first specific aspect of the present invention, a frequency synthesizer is provided for a mobile unit of a time division multiple access (TDMA) cellular communication system wherein each of a plurality of cell site stations is assigned a channel of unique frequency for carrying a sequence of transmit/receive slots and idle slots. The frequency synthesizer comprises a reference pulse source for generating pulses of reference frequency, a phase comparator for generating a phase difference signal indicative of a phase difference between two input signals applied thereto, first and second loop filters, first switch means for selecting one of the first and second loop filters, second switch means for establishing a connection between the output of the phase comparator and the selected loop filter in response to a close-loop command signal to cause the selected loop filter to develop a voltage according to the phase difference signal and clearing down the connection in response to an open-loop command signal, a voltage-controlled oscillator connected to the selected loop filter for generating an output signal at a frequency corresponding to the voltage developed by the selected loop filter, a frequency divider connected to the voltage-controlled oscillator for producing an output pulse at a submultiple of the frequency of the voltage-controlled oscillator, and a phase alignment circuit for establishing initial phase alignment between an output pulse from the frequency divider and a reference pulse from the reference pulse source in response to an enable signal and applying the phase-aligned signals to the phase comparator as the two input signals. A controller is provided for (a) generating the closed-loop command signal,

causing the first switch means to select the first loop filter, and controlling one of the reference pulse source and the frequency divider to establish a channel between the mobile unit and a first cell site station, (b) generating the open-loop command signal during a transmit/receive slot of the established channel to thereby allow signals to be exchanged with the first cell site station in an open loop mode of the synthesizer, (c) generating the close-loop command signal, causing the first switch means to select the second loop filter, controlling one of the reference pulse source and the frequency divider and generating the enable signal during an idle slot of the established channel to receive a signal from a second cell site station, and (d) causing the first switch means to select the first loop filter, controlling one of the reference pulse source and the frequency divider and generating the enable signal during the idle slot so that signals can be exchanged again with the first cell site station during a subsequent transmit/receive slot of the channel.

According to a second specific aspect of the present invention, the frequency synthesizer includes a phase-lock detector connected to the phase comparator for producing a phase-lock detect signal when the phase difference indicates that the two input signals are locked in phase and means for generating a steady-state detect signal indicating that the voltage developed in the loop filter has attained a substantially steady value. A gate circuit generates a signal when the phase-lock detect signal and the steady-state detect signal are simultaneously present. A controller is provided for (a) generating said closed-loop command signal and controlling one of the reference pulse source and the frequency divider to establish a channel between the mobile unit and a first cell site station, (b) generating said open-loop command signal in response to the signal from said gate means to allow signals to be exchanged with the first cell site station in an open loop mode of the synthesizer during a transmit/receive slot of the established channel, (c) generating said close-loop command signal, controlling one of said reference pulse source and the frequency divider and generating said enable signal during an idle slot of the established channel to receive a signal from a second cell site station, and (d) controlling one of said reference pulse source and the frequency divider and generating said enable signal during said idle slot so that signals can be exchanged again with the first cell site station during a subsequent transmit/receive slot of the channel.

According to a third specific aspect, the frequency synthesizer includes a delay circuit for delaying the output of the frequency divider for a predetermined interval, and a phase-lock detector connected to the phase comparator for producing a phase-lock detect signal when the phase difference indicates that the two input signals are locked in phase. A switch is provided for exclusively connecting the reference pulse to the phase alignment circuit in response to a first mode signal or exclusively connecting the output of the delay circuit to the phase alignment circuit in response to a second mode signal. A controller is provided for (a) operating the switch means to apply the reference pulse to the second input terminal of the phase comparator, and operating one of the reference pulse source and the frequency divider so that a channel is established between the mobile unit and a first cell site station, (b) operating the switch means to apply the output signal of the delay means to the second input terminal of the phase comparator when the phase difference indicates that signals at the first and second input terminals of the phase comparator are locked in phase to allow signals to be exchanged between the mobile unit and the first cell site station in an open-loop mode during a

transmit/receive slot of the channel, (c) operating the switch means to apply the reference pulse to the second input terminal of the phase comparator, and operating one of the reference pulse source and the frequency divider during an idle slot of the channel to receive a signal from a second cell site station, and (d) operating one of the reference pulse source and the frequency divider so that signals can be exchanged between the mobile unit and the first cell site station during a subsequent transmit/receive slot of the channel.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be described in further detail with reference to the accompanying drawings, in which:

FIG. 1 is a block diagram of a prior art frequency synthesizer;

FIG. 2 is a block diagram of a frequency synthesizer and associated TDMA cellular mobile circuitry according to a first embodiment of the present invention;

FIG. 3 is a timing diagram associated with the first embodiment of the present invention;

FIG. 4 is a flowchart diagram associated with the first embodiment of the present invention;

FIG. 5 is a block diagram of a frequency synthesizer and associated TDMA cellular mobile circuitry according to a second embodiment of the present invention;

FIG. 6 is a circuit diagram showing details of a steady state detector;

FIG. 7 is a timing diagram associated with the second embodiment of the present invention;

FIG. 8 is a flowchart diagram associated with the second embodiment of the present invention;

FIG. 9 is a block diagram of a frequency synthesizer and associated TDMA cellular mobile circuitry according to a third embodiment of the present invention;

FIG. 10 is a timing diagram associated with the third embodiment of the present invention; and

FIG. 11 is a flowchart diagram associated with the third embodiment of the present invention.

#### DETAILED DESCRIPTION

Referring now to FIG. 2, there is shown a mobile unit according to a first embodiment of the present invention. The mobile unit comprises a digital radio transceiver 22 that transmits an uplink burst in a transmit slot of a TDMA frame to a host cell site station and receives a downlink burst in a receive slot of the frame from the cell site. The transmit section (transmitter) of transceiver 22 is powered through a power line 50 from a power supply (battery) unit 20 under the control of a power saving circuit 21 and the receive section (receiver) of the transceiver is powered through a power line 51 under the control of power saving circuit 21. A controller 23 is connected to the transceiver 22 to monitor the operating state of the mobile unit and provides power-saving control signals (standby/talk mode and power saving on/off command) to power saving circuit 21 and timing control signals (sync enable and close/open command) to a phase-locked loop 30 in a manner as will be described later. A signal level detector 24 is connected to transceiver 22 and controller 23 to measure the level of a TDMA frame received by the mobile unit.

The phase-locked loop **30** includes a direct digital synthesizer **31** for generating a reference frequency, an initial phase alignment circuit, or synchronizer **32**, a phase comparator **33**, a loop control switch **34** which is connected through a resistor **35** to a loop filter control switch **40**, and a voltage controlled oscillator **36** which generates the local carrier of the transceiver **22**. A variable frequency divider **37** is connected to the output of the VCO **36**. Loop filters **41** and **42** of resistor-capacitor network are connected to the outputs of switch **40** to be selectively connected across the input and ground terminals of VCO **36** in accordance with a loop filter switching signal from controller **23**. The loop filter **41** is normally connected to the VCO when the transceiver is tuned to a speech channel. The loop filter **42** is switched into circuit with the VCO during an idle slot for seeking an idle channel (channel search mode) for possible hand-off to an adjacent cell site. As will be described, the effect of the loop filter **41** is to hold the voltage developed in the loop filter capacitor during a transmit/receive slot and use it again during the next transmit/receive mode. The voltage reapplied to the VCO from the loop filter **41** is approximately the same voltage which the VCO received at the end of the previous transmit/receive mode so that the frequency of the divider **36** can be made to match the reference frequency in a short period of time prior to the next transmit/receive mode.

Power saving circuit **21** supplies DC voltage from source **20** to the power draining units of the phase locked loop **30** such as DDS **31**, phase comparator **33** and frequency divider **37** via a power line **52** and turns off the power line for power savings purpose in response to a power saving control signal from the controller **23**. The remaining parts of the phase locked loop **30** are directly powered by the voltage source **20** through power line **53**.

Direct digital synthesizer **31** supplies sharply defined rectangular pulses at the reference frequency to the initial phase synchronizer **32**. This synchronizer comprises D flip-flops **44**, **46** and AND gates **45**, **47**. Flip-flop **44** receives the outputs of DDS **31** and VCO **36** at its data and clock inputs, respectively, and produces a high-level Q output in response to a pulse from the VCO if the binary level at the data input is high or a low-level Q output in response to the VCO output if the data input's binary level is low. The output of DDS **31** is also applied to the data input of flip-flop **46** to produce a high-level Q output in response to a sync enable pulse applied to its clock input from the controller **23**. AND gates **45** and **47** receive this sync enable pulse at their first input as well as the output signals of flip-flop **44** and frequency divider **37** respectively at their second input. AND gate **45** thus produces a pulse whose leading and trailing edges are synchronized to the VCO output pulse. The output of flip-flop **46** is applied to frequency divider **37** as an enable pulse to cause it to start a count operation on the input from the VCO to produce an output frequency which is a submultiple of the VCO frequency, which submultiple being varied in response to a channel selection signal from controller **23**. The output of frequency divider **37** causes AND gate **47** to produce a pulse whose leading and trailing edges are timed with the output pulse of frequency divider **37**, and hence with the VCO output pulse. Thus, the initial phases of the outputs of flip-flop **44** and frequency divider **37** are synchronized to each other immediately following the leading edge of the sync enable pulse as shown in FIG. 3. The output flip-flop **44** is passed through AND gate **45** to the reference input of phase comparator **33** and the output of frequency divider **37** is passed through AND gate **47** to the second input of phase comparator **33**.

Phase comparator **33** is any of conventional logic circuits which produces a high-level output at one of two output terminals when one of the inputs to the comparator is advancing with respect to the other and produces a high-level output at the other output terminal when the input phase relation is reversed. A circuit known as a charge-pump is connected to the output terminals of the logic circuit for charging a loop filter when one of the outputs is driven high and drawing a charge from the loop filter when the other output is driven high.

When the loop control switch **34** is in a closed state, the charge-pump of phase comparator **33** pumps a charge into or draws a charge from the capacitor of the selected loop filter, so that a voltage corresponding to the phase difference is developed at the junction between resistor **35** and the input of switch **40** and this voltage is applied as a frequency control signal to the VCO **36**.

Variable frequency divider **37** is controlled by a channel selection signal from the controller **23**. For possible hand-off operation, channels of adjacent cell sites must be monitored when a communication proceeds on a certain speech channel with a host cell site by briefly switching the frequency of the frequency divider **37** to the channel of an adjacent cell site in response to a channel selection signal from the controller **23**. During this channel search mode, a filter switching signal is supplied from the controller **23** to the switch **40** to connect the loop filter **42**, instead of loop filter **41**, to the VCO, and a closed-loop command signal is supplied from the controller **23** to the loop control switch **34** to connect the phase comparator **33** to the selected loop filter **42**.

Note that, instead of controlling the frequency divider **37**, the direct digital synthesizer **31** may be controlled by the channel selection signal from the controller as indicated by a bus **43**.

The TDMA cellular communication system of the present invention uses a frame format as shown in FIG. 3. Each cell site of the system is allocated a unique frequency according to the system's frequency reuse plan. The frequency assigned to each cell site carries a TDMA frame comprising a plurality of 20-ms two-way channels, each comprising a receive slot for receiving a burst from the cell site, a transmit slot for transmitting a burst from the mobile unit, and an idle timeslot in which the mobile unit is allowed to make a channel search in preparation for a possible hand-off from the current cell to an adjacent cell.

The operation of the first embodiment will be given below with reference to a flowchart shown in FIG. 4 in which a sequence of operational steps performed by the controller **23** is illustrated. Program execution starts with decision block **60** which initializes the adjacent channel index variable "i" to one. Exit then is to block **61** to check to see if the mobile unit is in a standby or a talking mode. If the controller **23** determines that the mobile unit is in a standby mode, it branches at block **61** to block **62** to cause the power saving circuit **21** to interrupt the power applied to the PLL power line **52**. This power interrupt mode is provided according to the conventional standby-mode periodic power-savings pattern so that the control slot of the TDMA frame can be accessed to determine whether there is an incoming call from the host cell site. More specifically, the standby-mode periodic power-savings pattern is such that power saving circuit **21** turns off the transmitter continuously during this mode to save its power consumption, and periodically turns on the receiver for an interval slightly longer than the TDMA frame period to allow the controller **23** to monitor the control slot of the TDMA frame of the current cell site, and then

turns it off for an interval much longer than the frame period to conserve the receive power.

During the standby mode, the controller **23** controls the filter switch **40** to connect the loop filter **41** to the VCO to allow the receiver to tune to channel frequency  $F_1$  of the current cell site. Control then advances to block **63** to open and close the loop control switch **34** in synchronism with the turn-off and turn-on timing of power line **52** (and hence, the receiver's turn-off and turn-on timing), and returns to block **61** to repeat the process. When the switch **34** is in a closed state, the capacitor of loop filter **41** is driven by the output of phase comparator **33** to develop a control voltage for the VCO. When it is open, the phase locked loop **30** operates in an open-loop mode, and the control voltage supplied previously to the VCO is maintained by the capacitor of the loop filter **41**. The close and open states of the PLL are repeated as long as the mobile unit is a standby mode according to the standby-mode periodic interruption pattern.

If control determines at block **61** that the mobile unit is in a talking mode, it branches to block **64** to increment the variable "i" to one, and proceeds to block **65** to determine whether power-on timing is approached. This timing is used to turn on the phase locked loop immediately prior to the beginning of an assigned idle slot to allow the phase locked loop to tune to a selected channel within the period of the subsequent idle slot. If the answer is negative at block **65**, control branches at block **72** to turn off the PLL power line **52**, and returns to block **61**. If the answer is affirmative, control branches to block **66** to turn on the PLL power line **52** (time  $t_0$ , FIG. 3). Exit then is to block **67** to apply a sync enable pulse to the initial phase synchronizer **32** of the PLL (at time  $t_1$ ) so that phase comparator **33** is supplied with phase-aligned input pulses. The establishment of this initial phase synchronization allows phase locked loop **30** to quickly converge to a stabilized state.

Controller **23** then proceeds to block **68** to supply a closed-loop command signal to the loop control switch **34** (at time  $t_2$ ) and apply a channel selection signal (change-to-F<sub>i</sub>) to variable frequency divider **37** and a filter switching signal to the switch **40** to connect the loop filter **42** to the VCO, instead of loop filter **41**. Phase locked loop **30** now operates in a closed loop using the loop filter **42**.

The receiver is thus tuned to the channel of an adjacent cell and the signal level of this channel is determined by the signal level detector **24** and the controller **23** is informed of this level to determine whether a hand-off is to be performed, which will be completed until time  $t_3$ . Controller **23** then supplies a channel selection signal (return-to-F<sub>1</sub>) to frequency divider **37** and a filter switching signal to filter control switch **40** (block **69**) to return to the current frequency  $F_1$  to connect the loop filter **41** to the VCO. Since the voltage maintained in the loop filter **41** during the channel search mode is substantially equal to the voltage, the initial phase synchronizer **32** can quickly resynchronize to the current channel, and the loop filter **41** keeps its capacitor voltage without being affected by the channel switching operation. No dielectric absorption problems thus occur in the loop filter capacitor, and the loop filter keeps its voltage during subsequent channel switching and open loop operation.

As a result, the phase-locked loop **30** can be stabilized again to frequency  $F_1$  immediately prior to the next receive slot. Control then proceeds to block **70** to apply an open-loop command signal to the loop control switch **34** and a PLL-power turn-off command to power saving circuit **21** to cause it to turn off the PLL power line **52** (time  $t_4$ ). Exit then

is to block **71** to check to see if  $i=k$ . If it is not, control returns block **61** to repeat the above process on the channels of the other adjacent cells, and if it is control returns to block **60** to repeat the process all over again. It is seen that during the period between times  $t_3$  and  $t_4$ , the loop filter **41** capacitor is driven in a phase-locked mode to update its voltage level for the subsequent open-loop operation.

When the talking mode proceeds, power saving controller **21** turns off the transmitter during an assigned receive slot as well as on an assigned idle slot and turns it on during an assigned transmit slot, while turning the receiver off during each transmit slot and turning it on during the assigned receive and idle slots.

FIG. 5 is a block diagram of a second embodiment of the present invention in which parts corresponding to those in FIG. 2 are marked with the same numerals as those used in FIG. 2, and the description thereof are omitted for simplicity. This embodiment differs from the first embodiment by the use of a single loop filter **80**, instead of the switched loop filters.

When channel switching occurs, a rapid voltage change would occur at the input of the loop filter **80**, and a dielectric absorption current flows, causing voltage fluctuations to occur in the loop filter. A steady state detector **82** is connected to the loop filter **80** to determine whether such voltage fluctuations are stabilized and converged to within a narrow voltage range. A phase-lock detector **83** is connected to the output of phase comparator **33** to detect a phase comparator output which indicates that a phase-lock condition is established in the loop and produce a phase-lock detect signal. The output signals of steady state detector **82** and phase-lock detector **83** are applied to an AND gate **84**, whose output is supplied to controller **23** as a signal to allow it to determine the time at which the phase locked loop is to be opened again.

FIG. 6 shows details of the steady state detector **82**. As illustrated, it comprises a voltage follower **85** connected to the loop filter **80**. The output of the voltage follower **85** is connected over two paths to comparators **87** and **88**, one being a delay-line path through a resistor-capacitor delay circuit **86** to the positive input of comparator **87** and to the negative input of comparator **88**, and the other being a direct path to the negative input of comparator **87** and the positive input of comparator **88**. The outputs of both comparators are applied to an AND gate **89** to produce a steady-state detect signal for coupling to the AND gate **84**. Comparators **87** and **88** both produce a logic-1 signal when the delayed output becomes smaller than the offset voltage of the comparators.

The operation of the controller **23** of FIG. 5 will be described with reference to a timing diagram and a flowchart respectively shown in FIGS. 7 and 8. Referring to FIG. 8, the operation of the controller is illustrated which differs from the previous embodiment in that it uses blocks **90** to **95** instead of blocks **68** to **70** of FIG. 4. During the open-loop mode prior to the turn-on of power line **52** at time  $t_0$ , the loop filter **80** maintains a constant voltage and the VCO **36** is driven with this voltage. At time  $t_0$ , the frequency divider **81** is turned on to receive the output of the VCO whose frequency is the same as the open-loop mode. Therefore, the frequency of the output of the frequency divider **81** is approximately the same as the frequency generated during the previous open-loop mode. In response to the application of a sync enable pulse to the PLL **30** at time  $t_1$  (block **67**), the output of frequency divider **81** and the reference input of phase comparator **33** are quickly brought into phase in the same manner as in the previous embodiment.

Control now proceeds to block 90 to close the switch 34 at time  $t_2$ . Exit then is to block 91 to apply a channel switching command to the frequency divider 81 at time  $t_3$  so that VCO 36 will then be caused to change its output frequency from  $F_1$  to  $F_i$  through a closed-loop mode of operation. When the phase locked loop 30 subsequently enters a phase lock state and the VCO frequency is stabilized to  $F_i$ , the output of AND gate 84 will switch to logic 1 as indicated at 84a in FIG. 7. However, the controller 23 ignores this signal. When the controller 23 completes a channel switching for a hand-off to an adjacent cell, it returns to the channel of the current cell at time  $t_4$  (block 92) by applying a control signal to the frequency divider 92 so that the VCO 36 switches its output frequency from  $F_i$  back to  $F_1$ . The switching of frequencies causes the phase lock loop 30 to unlock again as at time  $t_3$  and the output of AND gate 84 goes low at time  $t_4$ . If the PLL 30 subsequently enters a phase lock state and the voltage at the loop filter 80 is stabilized at time  $t_5$ , controller 23 will receive a logic-1 output 84b from the AND gate 84 as it executes block 93 and turns off the switch 34 (block 94). Controller 23 proceeds to block 95 to turn off the PLL power line 52 at time  $t_6$  prior to the next receive slot. The PLL 30 is open again and the VCO 36 is continuously supplied with a voltage maintained by the loop filter 80.

A third embodiment of the present invention is shown in FIG. 9 in which parts corresponding to those in the previous embodiments are marked with the same numerals. In this embodiment, a phase locked loop 100 comprises a direct digital synthesizer 101 whose output frequency is controlled by the channel switching command of the controller 23. The output of the DDS 101 is coupled through the first terminal of a changeover switch 102 to an initial phase synchronizer 103 comprising D flip-flops 110, 112 and AND gates 111, 113 identical in structure to the synchronizer 32 of the previous embodiments. The outputs of synchronizer 103 are compared by phase comparator 104 whose output is coupled via a loop filter 105 to a VCO 106. A divide-by-n frequency divider 107, which is arranged to be enabled by the output of flip-flop 112, is connected to the output of VCO 106 to supply its output to AND gate 113 and to an n-pulse delay circuit 108.

In the delay circuit 108 a divide-by-(a/n) frequency divider 120 is arranged to be enabled by the output of flip-flop 112 to receive the output of the VCO 106 through a delay buffer 121. The output of frequency divider 120 is applied to the clock inputs of D flip-flops 122<sub>1</sub> through 122<sub>an</sub> which are connected in successive stages to form a delay line in which "n" pulses of frequency divider 107 are stored. The first stage flip-flop 122<sub>1</sub> receives the output of frequency divider 107 at its data input. Each flip-flop receives the output of the preceding stage and applies its output to the data input of the next stage. The last stage flip-flop 122<sub>an</sub> applies its output to the second terminal of changeover switch 102. During closed-loop modes, the switch 102 is positioned to the first terminal for coupling the output of DDS 101 to the phase synchronizer 103, and during open-loop modes, it is switched to the second terminal for coupling the output of flip-flop 122<sub>an</sub> in response to a switching control signal from the DDS/DELAY port of the controller 23. A phase-lock detector 130 is connected to the output of phase comparator 104 to detect a phase lock state of the loop and communicates this fact to the controller 23. As will be understood, since phase comparator 104 and frequency divider 107 are permanently powered to activate the phase lock loop, it is only the DDS 101 that is made inactive during transmit and receive slots and made active through power line 52 during specified idle slots.

The operation of the controller 23 of FIG. 9 will be described with reference to a timing diagram and a flowchart respectively shown in FIGS. 10 and 11. Referring to FIG. 11, the operation of the controller is illustrated which differs from the first embodiment in that it uses blocks 140 to 147 instead of blocks 66 to 70 of FIG. 4.

Initially, the output of DDS 101 is at frequency  $F_1$  and applied through synchronizer 103 to phase comparator 104 where it is phase-compared with the output of frequency divider 107. When the loop is phase-locked, the controller 23 is notified of this fact from phase-lock detector 130 to cause the changeover switch 102 to switch from the first to the second terminal, so that the phase lock loop 100 is switched from an externally-driven, closed loop mode to a self-driven, closed loop mode in which the frequency divider 107 is producing a pulse at  $1/n$  of frequency  $F_1$  as indicated by hatched pulses in FIG. 10. Thus, the phase lock loop 100 is usually in the self-driven mode to allow the DDS 101 to be turned off.

Following the execution of block 65, control exits to block 140 to turn on power line 52 to activate the DDS 101 while supplying to it a channel switching command which causes it to tune to frequency  $F_i$  and the switch 102 is controlled to change its position to the first terminal for coupling the delayed output of frequency divider 107. Control advances to block 141 to place a logic-1 level to its sync enable port at time  $t_1$  (see also FIG. 10). The output of frequency divider 107 will then be brought into phase with the output of DDS 101 and begins to generate a series of pulse at  $1/n$  of the frequency  $F_i$  of an adjacent cell. After a sequence of "n" pulses has been delivered from the delay circuit 108 during a period from time  $t_1$ , the inputs of phase comparator 104 begin to match in frequency and in phase, and a phase lock condition is detected by phase lock detector 130, producing a first phase-lock signal 130a at time  $t_2$ . Controller 23 detects this signal as it subsequently executes decision block 142, and proceeds to block 143 to switch the sync enable port to low level.

Exit then is to block 144 to cause DDS 101 to return to the original setting so that the output of VCO 107 is returned to frequency  $F_1$  and cause the changeover switch 102 to move to the second terminal for coupling the output of delay circuit 108 to the phase synchronizer 103 (at time  $t_3$ ). Since one of the inputs of the phase comparator 104 changes in frequency while the frequency of the other input remains unchanged until "n" pulses are output from the delay circuit 108, the phase lock loop 100 unlocks and the output of phase-lock detector 130 goes low at time  $t_3$  (FIG. 10). Control then proceeds to block 145 to switch the binary state of the sync enable port to high again at time  $t_4$  to enable a phase match to quickly occur between signals at the phase comparator inputs. Control then executes block 146 by examining the output of phase lock detector 130. Following the delivery of "n" pulses from the delay circuit 108 that have been generated within the period after time  $t_4$ , the phase lock loop 100 will be locked at time  $t_5$  and the phase lock detector 130 informs this fact to controller 23 with a second phase-lock signal 130b, which responds to it by executing block 147 in which it instructs the power saving circuit 21 to turn off the PLL power line 52.

What is claimed is:

1. A frequency synthesizer of a mobile unit for a time division multiple access cellular communication system, said system having a plurality of cell site stations each being assigned a channel of unique frequency for carrying a sequence of transmit/receive slots and idle slots, the frequency synthesizer comprising:

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a reference pulse source for generating a reference pulse;  
 a phase comparator having a first input terminal responsive to said reference pulse, a second input terminal and an output terminal;  
 first and second loop filters;  
 a voltage-controlled oscillator;  
 first switch means for establishing a connection between the output terminal of said phase comparator and the loop filters;  
 second switch means for connecting one of said first and second loop filters to said voltage-controlled oscillator; and  
 a frequency divider connected to said voltage-controlled oscillator for supplying a pulse at a submultiple of an output frequency of the voltage-controlled oscillator to the second input terminal of said phase comparator;  
 a controller for:  
 a) activating said reference pulse source and said frequency divider and operating said first switch means to establish said connection;  
 b) operating said second switch means to exclusively connect said first loop filter to said voltage-controlled oscillator, and operating one of the reference pulse source and the frequency divider so that a channel is established between the mobile unit and a first cell site station;  
 c) operating said first switch means to clear said connection and deactivating said reference pulse source and said frequency divider to thereby allow signals to be exchanged between the mobile unit and said first cell site station during a transmit/receive slot of said channel in a power saving mode;  
 d) activating said reference pulse source and the frequency divider, operating said first switch means to re-establish said connection, operating said second switch means to exclusively connect said second loop filter to said voltage-controlled oscillator, and operating one of the reference pulse source and the frequency divider during an idle slot of the channel to receive a signal from a second cell site station;  
 e) operating one of the reference pulse source and the frequency divider and operating said second switch means to exclusively connect said first loop filter to said voltage-controlled oscillator so that signals can be exchanged between said mobile unit and the first cell site station during a subsequent transmit/receive slot of the channel; and  
 f) repeating the steps (c) to (e).

2. A frequency synthesizer of a mobile unit for a time division multiple access cellular communication system, said system having a plurality of cell site stations each being assigned a channel of unique frequency for carrying a sequence of transmit/receive slots and idle slots, comprising:

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a reference pulse source for generating pulses of reference frequency;  
 a phase comparator for generating a phase difference signal indicative of a phase difference between two input signals applied thereto;  
 first and second loop filters;  
 first switch means for selecting one of the first and second loop filters;  
 second switch means for establishing a connection between the output of said phase comparator and the selected loop filter in response to a close-loop command signal to cause the selected loop filter to develop a voltage according to said phase difference signal and clearing down said connection in response to an open-loop command signal;  
 a voltage-controlled oscillator connected to the selected loop filter for generating an output signal at a frequency corresponding to the voltage developed by the selected loop filter;  
 a frequency divider connected to said voltage-controlled oscillator for producing an output pulse at a submultiple of the frequency of the voltage-controlled oscillator;  
 a phase alignment circuit for establishing initial phase alignment between an output pulse from said frequency divider and a reference pulse from said reference pulse source in response to an enable signal and applying the phase-aligned signals to said phase comparator as said two input signals; and  
 a controller for (a) generating said closed-loop command signal, causing said first switch means to select the first loop filter, and controlling one of the reference pulse source and the frequency divider to establish a channel between the mobile unit and a first cell site station, (b) generating said open-loop command signal during a transmit/receive slot of the established channel to thereby allow signals to be exchanged with the first cell site station in an open loop mode of the synthesizer, (c) generating said close-loop command signal, causing said first switch means to select the second loop filter, controlling one of said reference pulse source and the frequency divider and generating said enable signal during an idle slot of the established channel to receive a signal from a second cell site station, and (d) causing said first switch means to select the first loop filter, controlling one of said reference pulse source and the frequency divider and generating said enable signal during said idle slot so that signals can be exchanged again with the first cell site station during a subsequent transmit/receive slot of the channel.

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